

Dynamic geometry and wall thickness of the aortic neck of abdominal aortic aneurysms with intravascular ultrasonography

Frank R. Arko, MD,^a Erin H. Murphy, MD,^a Chad M. Davis III, BS,^a Eric D. Johnson, MS,^b Stephen T. Smith, MD,^a and Christopher K. Zarins, MD,^c Dallas, Tex; and Portola Valley and Palo Alto, Calif

Background: It is commonly assumed that the aortic wall deforms uniformly and has uniform wall thickness about the circumference. The purpose of this study was to evaluate the aortic wall motion and thickness in the infrarenal aortic neck of patients with abdominal aortic aneurysms who were undergoing endovascular repair (EVAR) and to compare the dynamic measurements of intravascular ultrasonography with the static measurements of computed tomographic angiography (CTA).

Methods: A total of 25 patients were evaluated before surgery with CTA and three-dimensional reconstructions on a Vitrea workstation, followed by intraoperative assessment of the proximal aortic neck with intravascular ultrasonography (IVUS) before EVAR. Infrarenal aortic neck dimensions on CTA were obtained at 1-mm intervals, but for the purposes of this study all dimensions on CTA were obtained 1 cm below the lowest renal artery. IVUS analysis of the proximal aortic neck was obtained with a 10-second recorded data loop of aortic wall motion. A Digital Imaging and Communications in Medicine viewer was used to view the recorded loop of aortic movement, and each image was captured and then evaluated with a SCION PCI Frame Grabber to determine aortic dimensions and wall thickness. IVUS diameters (250 measurements of each aorta) were recorded through a full continuous cardiac cycle from the epicenter of the lumen (maintaining the left renal vein in its normal anatomic configuration) in an anteroposterior (AP) direction in the area of greatest wall movement and 90° perpendicular to this direction (lateral movement).

Results: There was significant variation in infrarenal aortic wall movement about the circumference, with 1.7 ± 0.6 mm (range, 0.6-2.7 mm) displacement in the AP direction and 0.9 ± 0.5 mm (range, 0.3-1.5 mm) displacement in the lateral direction ($P < .001$). Aortic wall thickness was greater in the region of increased AP wall motion than in the area of lesser lateral wall motion (2.3 ± 0.6 mm vs 1.2 ± 0.3 mm; $P < .001$). There was no difference between the IVUS and CTA aortic neck measurements (25.5 vs 25.6 mm; not significant) during the midpoint of the cardiac cycle of IVUS. However, at peak systole, IVUS recorded a greater diameter than CTA (26.4 vs 25.6 mm; $P < .001$), and at end-diastole, IVUS recorded a smaller diameter than CTA (24.7 vs 25.6 mm; $P = .01$).

Conclusions: The infrarenal neck of aortic aneurysms deforms anisotropically during the cardiac cycle. The greatest displacement is in the AP direction and corresponds with a significantly greater wall thickness in this area. The magnitude of cyclic change in aortic diameter can be as high as 11%. Further evaluation of proximal aortic neck wall motion after EVAR is warranted to determine the interaction of various stent designs and the aortic wall. (J Vasc Surg 2007;46: 891-7.)

It is well established that arterial wall biomechanics (ie, wall motion, wall stress, and wall thickness) contribute to the localization of atherosclerotic plaques and aneurysm development/progression.¹⁻⁵ Hemodynamic factors have been linked to the localization of atherosclerotic plaque formation in areas of low shear stress and shear separation in the carotid, aortic, femoral, and coronary arteries.⁶

Furthermore, the elastic properties of the aortic wall permit deformation of the aorta with pulsatile blood

flow: ie, the aorta relaxes during diastole and expands during systole. It is commonly assumed that the aortic wall expands and relaxes concentrically with the cardiac cycle and has uniform wall thickness about the circumference. However, a review of recent literature provides evidence to the contrary, suggesting an unequal circumferential deformation of the aorta during the cardiac cycle.¹⁻⁵ Because successful aneurysm exclusion is dependent on a complete seal at the level of the infrarenal aortic neck, uneven aortic wall motion and variable cyclic strain at this location could result in intermittent or constant pressurization of the aneurysmal sac (endotension), aneurysmal enlargement, and endoleak.¹

Contrast-enhanced computed tomographic angiography (CTA) is the most commonly used imaging modality for preoperative assessment of aortic aneurysm size and aortic neck dimensions for endograft sizing. Dynamic conformational changes occurring during the cardiac cycle are not captured with CTA or magnetic resonance angiography (MRA). Recent studies have demonstrated that the

From the Divisions of Vascular and Endovascular Surgery, University of Texas Southwestern Medical Center,^a Crux Biomedical Engineering,^b and Stanford University Medical Center.^c

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Reprint requests: Frank R. Arko, MD, Chief, Endovascular Surgery, Department of Surgery, University of Texas Southwestern Medical Center, 5909 Harry Hines Blvd, Dallas, TX 75903 (e-mail: frank.arko@utsouthwestern.edu).

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maximum thoracic aortic diameter may change more than 10% (up to 17.8%) during the cardiac cycle in the landing zones for thoracic aortic endograft placement.⁷ Similar dynamic changes have been shown to occur in the infrarenal aortic neck, and these changes have been noted to persist even after placement of an aortic endograft.^{1,5} Recognizing these pulsatile changes and considering the non-uniform cyclic diameter changes in the infrarenal aortic neck may help the design of endovascular devices with improved proximal seal and lower rates of endoleak and graft migration.⁸⁻¹²

Several imaging modalities have been used to study arterial wall motion, aortic cyclic strain, and dynamic size changes during the cardiac cycle, including intravascular ultrasonography (IVUS), dynamic computed tomography (CT)/CTA, dynamic magnetic resonance imaging/MRA, cardiac-gated magnetic resonance, and conventional digital subtraction angiography.¹⁰⁻¹⁴ In this study, IVUS recordings of aortic wall motion in the anteroposterior (AP) and lateral dimensions of the infrarenal aorta were measured before endograft placement. In addition to the specific geometry of the deformation of the aorta during the cardiac cycle, we measured aortic wall thickness in the anterior and lateral walls of the aorta in the areas of maximum and minimum movement, respectively.

METHODS

Patients. Between September 2004 and 2006, a total of 155 patients underwent endovascular aneurysm repair (EVAR) at our institution. Of these, 25 consecutive patients with a minimum neck length of 15 mm and a neck angulation of less than 30° (noncalcified necks) were evaluated before surgery with CTA and three-dimensional reconstructions by using a Vitrea (Vital Images, Inc, Minnetonka, Minn) workstation, followed by intraoperative assessment of the proximal aortic neck with IVUS.

CTA measurements. All preoperative examinations were performed with a 64-slice multidetector CT scanner after administration of 150 mL of iodinated contrast medium injected at 4 mL/s. Images were acquired at a pitch of 6.0 with 1-mm nominal section thickness with delayed images. Standardized evaluations of the axial, multiplanar, and three-dimensional reconstructions were performed. The CTA was not electrocardiogram gated. Infrarenal aortic neck dimensions on CTA were obtained at 1-mm intervals throughout the length of the aorta. For the purposes of this study, the infrarenal neck diameter 1 cm below the lowest renal artery was used and corresponded to a similar location with intraoperative IVUS measurements. Sizing measurements were performed perpendicular to the central lumen by using preoperative static CTA. Measurements were obtained from the inner wall to the inner wall in the AP and lateral directions, corresponding to the measurements in the similar directions on IVUS.

IVUS measurements. IVUS was performed with a Volcano (Rancho Cordova, Calif) 8.35-MHz Visions 8.2F catheter. Before EVAR and before insertion of the endograft, an IVUS catheter was introduced over an 0.035-in stiff wire

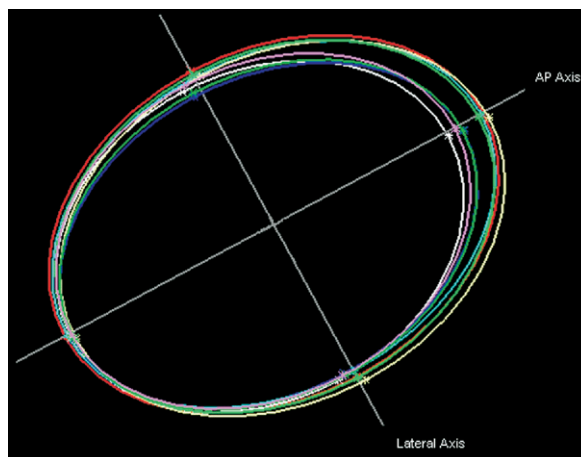


Fig 1. Luminal changes of the aortic circumference through a single cardiac cycle demonstrate the anisotropic movement of the aortic neck of an abdominal aortic aneurysm. Notice the significantly greater movement in the anteroposterior (AP) axis as compared with the lateral axis as labeled.

through a 30-cm 9F sheath and advanced to the level of the left renal vein. The long sheath and stiff wire were used to maintain the IVUS catheter as close to the central lumen as possible. Once the left renal vein was identified, the image was rotated to position the left renal vein anteriorly in its normal anatomic configuration. The lowermost renal artery was then identified, and a 1-cm pullback was used to ensure that the level of measurement corresponded to the level of the CTA measurement; the catheter was kept oriented in the normal anatomic position. This was the only area of the infrarenal neck that was measured. The video loop was captured with the gain set at 40 to delineate more accurately the adventitia and the periaortic tissues. A 10-second recorded data loop of aortic wall motion was then recorded at this level for subsequent analysis (Fig 1). IVUS was excellent for delineating the luminal surface of the blood tissue interface for determining diameter and area measurements. IVUS was less clear in delineating the adventitia and periaortic tissues as a result of the similar impedance properties of the tissues involved to determine wall thickness, especially in the posterior wall of the aorta that abuts the spine. Thus, the aortic wall thickness was not measured in this area. However, the anterior and lateral walls, where there is space between the aorta and adjacent structures, allowed for measuring the thickness of the wall. Aortic wall thickness was measured only during diastole.

Analysis of IVUS data. A Rubo Digital Imaging and Communications in Medicine viewer was used to view the recorded loop of aortic wall movement. Evaluation of the recorded loop allowed for frame-by-frame still-image measurements throughout the cardiac cycle, thus allowing for area and diameter measurements. Each image through a single cardiac cycle was then captured and analyzed with Scion

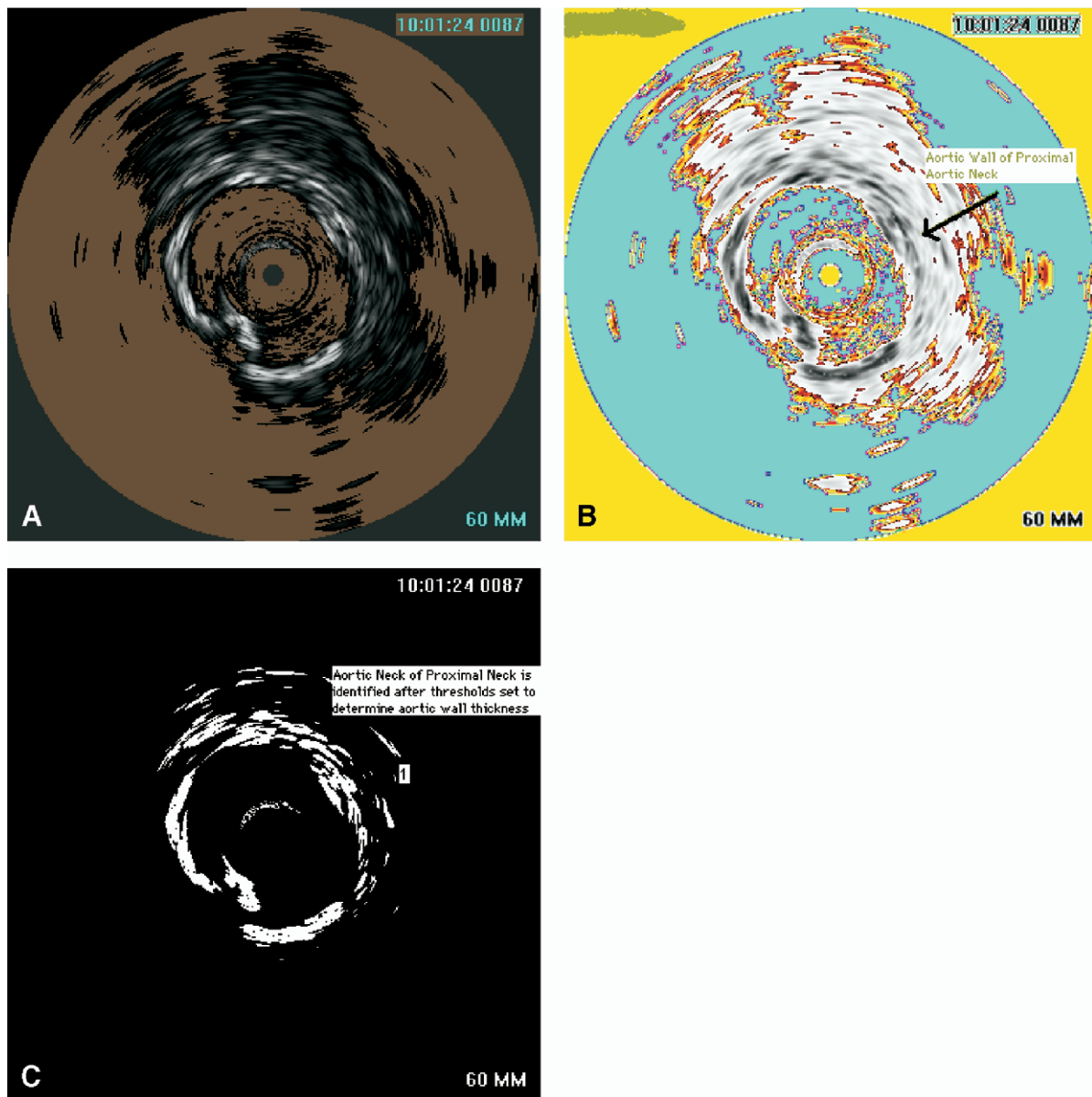


Fig 2. **A**, Original image of intravascular ultrasonography (IVUS) captured with the Digital Imaging and Communications in Medicine viewer. During IVUS, the gain was set at 40 and then saved as a bitmap image. **B**, The image was then opened with Scion PCI frame grabber, and the image is then inverted. Notice in both images that the IVUS catheter is in the central lumen of the vessel. **C**, Thresholds are then set on the inverted image to 146 on Scion PCI frame grabber to estimate the aortic wall thickness.

imaging software (NIH Image). Using this software allowed for a negative of each image to be created to fully delineate vessel thickness, and thresholds were set at 140 (Fig 2). The minimum and maximum aortic lumen diameters along two axes through the center of the aortic lumen were measured. Diameters (250 measurements) were recorded through a full continuous cardiac cycle from the epicenter of the lumen (the left renal vein was maintained in its normal anatomic configuration) in the AP and lateral wall and compared with CTA. Measurements were obtained from the

inner wall to the inner wall on both IVUS and CTA for this study. The lumen was then bounded, and the total vessel area was assessed quantitatively in square millimeters. Furthermore, the wall thickness of the aorta, measured from the inner wall to the outer wall, was obtained from the anterior aortic wall, where the movement was greatest, and the lateral aortic wall, where movement was minimal, during diastole. This was done again by using the inverted images, which allowed for easy delineation of the aortic wall. Each frame was independently reviewed by two blinded observers to evaluate diameter

Table I. Intravascular ultrasonography aortic neck morphology

Variable	Diastole	Systole	P value
Aortic neck diameter			
Lateral axis	25.0 ± 0.9	25.9 ± 1.1	<.05
Anteroposterior axis	24.7 ± 2.3	26.4 ± 2.5	<.001
Aortic neck area (mm ²)	485 ± 56	536 ± 63	<.001

Data are mean ± SD.

Table II. Intravascular ultrasonography aortic neck morphology

Variable	Anteroposterior axis	Lateral axis	P value
Variation in aortic wall movement (mm)	1.7 ± 0.6	0.9 ± 0.5	<.001

Table III. Aortic wall thickness

Variable	Anterior wall	Lateral wall	P value
Aortic wall thickness (mm)	2.3 ± 0.6	1.2 ± 0.3	<.001

changes, area changes, and wall thickness. Aortic wall thickness was measured only on IVUS and not on CTA.

Statistical analysis. Data on diameter, area, and wall thickness are expressed as mean ± SD. Changes in area and diameters were evaluated by using a Student *t* test for paired data. IVUS and corresponding CTA measurements were compared by using the Student *t* test as well. Changes of the same variable (aortic wall motion) were compared by using analysis of variance for repeated measurements. Analyses of measurement method comparison data according to Bland and Altman were performed to analyze repeatability and to compare measurements by two observers. A *P* value <.05 was considered statistically significant.

RESULTS

CTA aortic and aortic neck morphology

The mean abdominal aortic aneurysm diameter was 58 ± 21 mm (range, 47-96 mm). The mean aortic neck diameter was 25.3 ± 2.6 mm (range, 21-28 mm) in the lateral direction and 25.6 ± 2.7 mm in the AP direction of orthogonal reformatted images. All results are shown in Tables I to III.

IVUS aortic neck morphology

Aortic neck diameter lateral axis. Aortic neck diameter in the lateral axis varied significantly throughout the cardiac cycle. During diastole the lateral aortic axis was 25.0 ± 0.9 mm (range, 19-26 mm), and during systole it was 25.9 ± 1.1 mm (range, 20-28 mm; *P* < .05). The interobserver repeatability coefficient was 0.9 mm. The intraobserver repeatability coefficients were 0.5 mm for

observer 1 and 0.7 mm for observer 2. Interobserver and intraobserver variability showed no significant differences within or between observers.

Aortic neck diameter AP axis. Aortic neck diameter in the AP axis varied significantly throughout the cardiac cycle. During diastole, aortic neck diameter in the AP axis was 24.7 ± 2.3 mm (range, 18-26 mm), and during systole it was 26.4 ± 2.5 mm (range, 19-28 mm; *P* < .05). The interobserver repeatability coefficient was 1.0 mm. The intraobserver repeatability coefficients were 0.7 mm for observer 1 and 0.9 mm for observer 2. Interobserver and intraobserver variability showed no significant differences within or between observers.

Aortic neck area. Aortic neck area changed significantly during the cardiac cycle. Aortic neck area changed from 485 ± 56 mm² to 534 ± 63 mm² during the cardiac cycle (*P* < .01). The interobserver repeatability coefficient was 26 mm². The intraobserver repeatability coefficients were 17 mm² for observer 1 and 19 mm² for observer 2. Interobserver and intraobserver variability showed no significant differences within or between observers.

Aortic wall movement. Infraarenal aortic wall movement varied significantly, with the greatest displacement in the AP direction: 1.7 ± 0.6 mm (range, 0.6-2.7 mm), compared with 0.9 ± 0.5 mm (range, 0.3-1.5 mm) in the lateral direction (*P* < .001).

Aortic wall thickness. Aortic wall thickness was greater in the anterior segment of the neck (2.3 ± 0.6 mm) in the region of increased AP wall motion than in the lateral segment of the neck (1.2 ± 0.3 mm; *P* < .001) in the area of less lateral wall motion.

Interobserver repeatability was 0.2 mm in the anterior segment of the neck and 0.3 mm in the lateral segment of the aortic neck. Intraobserver repeatability coefficients were 0.3 and 0.2 mm for observer 1 in the anterior segment and 0.4 and 0.2 mm for observer 2 in the lateral segment. Interobserver and intraobserver variability showed no significant differences within or between observers.

Comparison of CTA and IVUS data

Aortic neck diameter. There was no difference between the IVUS and CTA aortic neck diameter (25.5 vs 25.6 mm; not significant) during the midpoint of the cardiac cycle. However, at peak systole, IVUS recorded a greater neck diameter than CTA (26.4 vs 25.6 mm; *P* < .001), and at end-diastole, IVUS recorded a smaller neck diameter than CTA (24.7 vs 25.6 mm; *P* = .01).

Aortic neck area. Aortic neck cross-sectional areas during diastole and systole were significantly different compared with the areas derived from CTA images. Aortic neck area measured by IVUS during diastole was smaller (485 ± 56 mm²) than aortic neck area measured on CTA (508 ± 63 mm²; *P* < .05). Aortic neck area measured by IVUS during systole was greater (536 ± 63 mm²) than aortic neck area measured on CTA (508 ± 63 mm²; *P* < .05).

DISCUSSION

Relatively recent advances in imaging techniques permit accurate three-dimensional image reconstruction for preoperative assessment of aortic dimensions for endograft sizing and aneurysm repair planning. CTA is used as the standard preoperative imaging modality to assess dimensions for endograft sizing and aneurysm repair. However, this imaging modality generates static images that do not account for the dynamic conformational changes with pulsatile blood flow during the cardiac cycle. Recent studies have demonstrated mean maximum diameter changes of greater than 10% (up to 17.8%) in the traditional landing zones for thoracic aortic graft placement. Because endovascular grafts are typically oversized by 10%, these pulsatile changes alone, or in combination with inaccurate measurements, could potentially lead to increased rates of endoleak and graft migration.⁷

Multiple imaging modalities are currently used for preoperative planning, and advances now allow us to look at the dynamic changes in aortic dimensions with pulsatile blood flow. Dynamic CTA, dynamic MRA, and IVUS have all been evaluated for detecting wall motion/wall strain and dynamic geometry changes of blood vessels during the cardiac cycle. Dynamic CT has been introduced as a method of assessing aortic wall changes with the cardiac cycle and has promising applicability in the future should these measurements become more routine. Recent studies have also validated the ability of dynamic MRA to accurately assess aortic wall motion, wall strain, and dynamic size change during the cardiac cycle.¹⁻⁶ In fact, dynamic MRA has demonstrated that significant aortic neck area changes occur during the cardiac cycle both before and after EVAR.¹⁵⁻¹⁹ Of note, both CTA and MRA have some limitations, including renal failure and radiation exposure with CTA and claustrophobia and nephrogenic fibrosing dermopathy in patients with chronic renal insufficiency with MRA. In addition, not all endografts can be evaluated with MRA.

The use of IVUS to evaluate aortic pulsatility and conformational changes during the cardiac cycle can avoid these limitations. In this study, all measurements were obtained at a predetermined anatomic location just below the level of the renal arteries. This location is generally assumed to be the most critical area of fixation for EVAR. Although some devices have suprarenal fixation components, including the Talent (Medtronic AVE, Santa Rosa, Calif) and the Zenith (Cook, Indianapolis, Ind), we did not specifically evaluate the suprarenal aorta in this study. Although suprarenal fixation may indeed be beneficial, we believe that the immediate infrarenal aorta remains the most critical area for obtaining proximal fixation, aortic seal, and prevention of type I endoleak. We therefore focused our research on this location. Certainly, this technology can be used to further evaluate the suprarenal aorta in future work.

Evaluation of the aortic neck diameter and area using IVUS as compared with CTA demonstrated that there was significant conformational change of the aorta in this location. Using IVUS, we demonstrated proximal aortic neck

diameter and area changes of nearly 11% during the cardiac cycle. Our findings are in line with others, who demonstrated a nearly 9% diameter change in the proximal aortic neck by using other imaging modalities, including cine CTA and MRA.¹⁻⁶ With undersized endografts, this could potentially lead to small intermittent proximal endoleaks that are not detected on routine imaging, including CTA or, MRA with endotension and resultant aneurysm growth.¹⁷

Certainly there have been reports of stent fractures, fabric erosions, suture breakage, and endograft erosions through native arteries. In a review of the current literature, including the aforementioned reports, it is obvious that there are significant changes that occur in the aortic neck after operative repair. This data may necessitate further evaluation regarding fatigue testing of implantable devices and future innovations for improved proximal fixation, including hooks and endostaples.

It is commonly assumed that the aortic wall contracts and expands concentrically with the cardiac cycle and has uniform wall thickness about the circumference. Recent studies have demonstrated that the aorta may not, in fact, deform uniformly in all dimensions.^{4,5,19} However, all these studies have routinely looked at nondiseased arteries. In this study, IVUS was used to evaluate the wall thickness in the areas of maximum and minimal movement of the infrarenal neck of aneurysmal aortas. We found that in the areas of maximal movement, wall thickness was the greatest. Previously, *in vivo* aortic wall motion has been measured at one level of the thoracic aorta and correlated with wall architecture. Qualitative and quantitative comparisons of the circumferential variation in both aortic thickness and motion demonstrated a direct relationship between wall structure and wall motion, with the greatest thickness in the area of greatest movement. This was studied by using magnetic resonance imaging and a specialized coil in a porcine model. Our study demonstrated similar results in the proximal aortic neck of aneurysms, with the greatest wall thickness occurring in the area of greatest movement. Additionally, taking into account the nonuniform cyclic diameter changes and thickness of the neck may help to design endovascular devices with lower rates of endoleak and graft migration.⁴ This may include the depth and location of active fixation components to the stent graft. With the aorta being nearly 47% thicker in the areas of greatest movement, future active fixation may require multiple sizes to get the preferred amount of penetration in these areas.

There are certainly limitations of this study for generalized use. First, we limited patients to those with long nonangulated necks without thrombus or calcium. This allowed for maintaining the IVUS catheter as close to the middle of the lumen as possible. Specifically, severely angulated necks were excluded because it is unlikely that the IVUS probe will be in the middle of the vessel, thus resulting in less precise measurements. Also, IVUS is not as consistent in clearly delineating adventitial and periaortic tissue interfaces as a result of the similar impedance properties of the tissues involved. We found this especially true along the posterior wall of the aorta and the spine.

Therefore, we did not attempt to measure the thickness of the posterior wall during this series as the aorta abuts the spine. However, in the anterior and lateral walls there was a clear delineation of the outer adventitia and surrounding structures. Furthermore, calcified necks and its associated shadowing would make it difficult to get accurate wall thickness measurements, and we avoided these types of neck in this study.

In this study, IVUS recordings of aortic wall motion in the AP and lateral dimensions of the infrarenal aorta were measured. In addition to the specific geometry of the deformation of the aorta during the cardiac cycle, we measured the wall thickness in the corresponding AP and lateral aortic dimensions. Specifically, we discussed findings regarding the preferential displacement of the infrarenal aortic wall in the AP dimension compared with the lateral dimension and the corresponding greater wall thickness in the anterior region of increased AP wall motion. The findings in this study may lead to improvements in operative planning and endograft design and durability (including accurate sizing, reduced endoleak occurrence, and reduced graft migration).

AUTHOR CONTRIBUTIONS

Conception and design: FRA, EHM, EDJ, CKZ

Analysis and interpretation: FRA, EHM, CMD, EDJ, STS

Data collection: FRA, EHM, CMD, EDJ

Writing the article: FRA, EHM, CMD, EDJ, STS, CKZ

Critical revision of the article: FRA, EHM, CMD, EDJ, STS, CKZ

Final approval of the article: FRA, EHM, CMD, EDJ, STS, CKZ

Statistical analysis: FRA, EHM, CMD, EDJ

Overall responsibility: FRA

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DISCUSSION

Dr W. Charles Sternbergh III (New Orleans, La). Dr Arko and his coauthors have examined an area that, as eloquently demonstrated in their manuscript, has been previously well described in the literature: the dynamic changes of the aortic neck diameter with the cardiac cycle and the potential variability in its measurement with different imaging modalities.

The authors studied 25 patients undergoing EVAR and measured aortic neck diameters with CTA and IVUS. The "take-home" results were as follows:

- No significant diameter difference between CTA and IVUS when the average (midcardiac cycle) IVUS measurement was used.
- By IVUS measurement, approximately 1.7-mm aortic neck diameter change from diastole to systole in the AP direction and 0.9-mm neck change in the lateral direction.
- Aortic wall thickness was greater in the AP direction.

So to borrow a piece of the authors' title for this manuscript, what are the implications of these data for endovascular repair? For

current devices, these data will not likely alter the use or sizing of endografts for EVAR. It does reconfirm that precise sizing of endografts is critical to long-term success. Our group has demonstrated that excessive endograft oversizing is associated with an increased rate of deleterious effects. The current study serves to underscore that relative undersizing is also dangerous: even a 10% oversize is probably inadequate. Thus, optimal oversizing is likely at 15% to 20%, which is already the current norm in most practices. I have the following questions for the authors:

1. First, a methodology question: was intra- or interobserver variability of the measurements examined? All of us who use electronic calipers to size endografts know only too well that the measured difference of a single millimeter, the differential in your study, is inherently subjective to a degree and can be altered with a slight pixel shift.
2. Have your findings influenced your choice of endograft design regarding active fixation vs passive fixation or the preference of self-expanding devices vs balloon expandable, if they were currently available? While the dynamic nature of the aortic wall would seem to intuitively favor a self-expanding design that could actively conform, previous balloon-expandable devices (Ancure; MEGs device) had excellent freedom from late endograft migration and proximal type I leak.
3. Finally, what are the implications of your data regarding newer endograft designs that rely on endovascular stapling for fixation? Should we consider adjusting the placement of those staples based on your data?

I would like to thank Dr Arko for the timely delivery of this well-written manuscript for my review and the program committee for the opportunity to discuss this article.

Dr Arko. With regard to interobserver and intraobserver variability with this method, we did study that in regard to looking at diameter, area, and wall thickness and found that there were no statistically significant differences within or between observers. With regard to comparing a balloon-expandable vs self-expanding stent graft for EVAR, I would think that a self-expanding stent would probably do better from a fatigue standpoint long-term than a balloon-expandable stent as a result of the motion of the aortic wall and the ability of the self-expanding stent to conform to these changes. However, as you have stated, the use of a Palmaz stent in that area has done quite well. I have personal experience of having balloon-expandable stents in the aortic neck following endograft placement that fail to expand when the aortic neck dilates as well as the stent graft. The balloon-expandable stent stays the same size as when you first deploy it, so you almost get a bit of a bull's-eye effect up in the neck in which the balloon-expandable stent appears underdeployed. Thus, while it is speculation, I believe that in the long-term the self-expanding stent will do better and will conform better with the proximal neck. Others have used MRA as well as CTA to look at the dynamic changes of the proximal aortic neck. They also demonstrated that there was roughly a 10% to 11% diameter change throughout the cardiac cycle, so I was happy to see that our results were similar. The one thing that they were not able to do in those studies—but probably could if they wished to—would be to look at the thickness of the aortic wall. With regard to future implications for devices, I do believe that if you are going to use endostapling devices, this information could be valuable in the design of the staple. It certainly appears from the data that the thickness of the aorta varies around its circumference, and thus a one-size-fits-all staple may not be appropriate. As the anterior wall is thicker by nearly 47%, two lengths of staple may be required to control the length and penetration of the staple.